Evolution of Tropical Cyclone Characteristics and Forecast Assessment

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LONG-TERM GOALS

The primary long-term goal is to understand how variabilities in the large-scale atmospheric environment influence tropical cyclone frequency, track and intensity characteristics. Because a tropical cyclone throughout its life cycle has the potential for impacting many fleet components, the research program is designed to apply to developing, mature, and decaying tropical cyclones. During the initial stages of tropical cyclone development, the structure and track characteristics can exhibit large variabilities that pose difficult forecast situations. Because decaying tropical cyclones often transition to fast-moving and rapidly-developing extratropical cyclones that may contain gale- or storm-force winds, special attention is given to improving understanding and prediction of the extratropical transition phase of a decaying tropical cyclone. A secondary long-term goal of this research is to measure the improvement in the utility of the tropical cyclone forecast products to shore- and sea-based assets that may be gained from increased understanding of the relationships between tropical cyclones and the large-scale environment in which they exist.

OBJECTIVES

Tropical cyclone frequency, motion, and structure characteristics depend on a variety of environmental and internal factors. The primary objectives of this research are to identify these factors and determine how they impact each of these tropical cyclone characteristics.

During June-October, the average time period between tropical cyclone formations over the tropical western North Pacific is 6.7 days. However, it is known that tropical cyclone formation occurs in clusters with time scales of one to two weeks (Gray 1985, Harr and Elsberry 1991). In this research, it is hypothesized that the mechanisms responsible for clustering of tropical cyclone activity are related to external and internal forcing mechanisms. External mechanisms are defined to act over larger space and longer time scales than that of a tropical cyclone, while internal mechanisms act over space and time scales that are similar to a tropical cyclone. Therefore, the primary scientific objectives are to identify each external and internal mechanism and define how they influence the clustering of tropical cyclone activity and inactivity.

During the initial and mature stages of a tropical cyclone, it has been hypothesized that the outer wind structure, which is important to understanding the motion of the tropical cyclone, is dependent on the growth, evolution, and decay of mesoscale convective systems (MCSs) and

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associated midlevel vortices. Therefore, the objective is to identify factors that control MCS evolution in the tropical cyclone environment, and the relationships between MCS development and the large-scale environment throughout the life cycle of the tropical cyclone.

When a tropical cyclone moves into the midlatitudes, it is hypothesized that the character of the midlatitude environment into which the tropical cyclone moves exerts the primary control on the extratropical transition of the tropical cyclone. Therefore, scientific objectives associated with this hypothesis are to identify the components of the midlatitude circulation that influence the tropical cyclone structure, and identify how the interactions between the midlatitude environment and tropical cyclone lead to either extratropical transition or decay of the tropical cyclone.

Increased understanding of the influences on tropical cyclone characteristics that are being sought in this research is important because of their impact on forecast operations, which must provide appropriate warnings to fleet units. Therefore, the objective is to assess the utility of tropical cyclone forecasts in relation to fleet operations. A description of forecast value in the context of fleet utility provides a metric that allows assessment of the impacts on forecast operations due to increased understanding of factors that influence tropical cyclone characteristics. Also, deficiencies in forecast utility may identify those environmental conditions that require further understanding to impact the forecast process in a positive manner.

APPROACH

The long-term goals and objectives of this research are structured such that a varied suite of technical approaches is required to adequately analyze important tropical cyclone characteristics, factors affecting these characteristics, and the value assigned to forecasts of these characteristics.

Harr and Elsberry (1995a,b) identified that the low-level, large-scale circulation over the tropical western North Pacific passes through alternate phases of circulation types that are favorable and unfavorable for tropical cyclone activity. The circulation patterns were identified as clusters with the duration of each cluster varying between 10 and 30 days and transitions between clusters occurring along preferred paths. The approach in the current research is to examine the subset of clusters associated with tropical cyclone inactivity in terms of mechanisms associated with the initiation, maintenance, and conclusion of inactive periods.

A major limitation to refinement of the roles played by MCS activity in influencing tropical cyclone structure is the lack of *in situ* data. The use of passive microwave observations from the Special Sensor Microwave Imager (SSM/I) on polar-orbiting satellites is one way to overcome this deficiency. However, SSM/I observations are only available when the satellite passes over the target MCS. To observe MCS life-cycle stages in a continuous manner, hourly visible and infrared imagery from geostationary satellites are required. The approach in this research has been to objectively track MCSs in the geostationary imagery and then use combinations of polar-orbiter microwave and geostationary infrared data to define MCS structural characteristics such as convective and stratiform cloud amounts, percent coverage, and rain rates. Furthermore, co-located microwave and infrared imagery are used to calibrate the infrared imagery, which allows for hourly estimates of these parameters to be defined from subsequent infrared images throughout the lifetime of the MCS.

As a tropical cyclone moves poleward, it may transition into an intense midlatitude cyclone that often contains gale- or storm-force winds. These potentially dangerous storms pose a serious threat to shore and maritime assets over midlatitude regions during seasons when extreme cyclonic activity does not normally occur. Therefore, it is logical to extend the study of tropical cyclone characteristics to this stage. For this component of the research, the approach is to assess the impact of various factors such as the evolving internal tropical cyclone features (e.g., convective activity, inner-core structure), midlatitude circulation into which the tropical cyclone is moving, and relative roles of upper- and lower-level processes on the transition from a tropical to an extratropical cyclone.

Definition of the utility of a forecast concerning the impact of tropical cyclone conditions on fleet assets is important for evaluating the forecast process and for determining what factors might provide increased value to the forecast operation. The approach in this research is to apply a benefit-risk model to the problem of assessing the potential accuracy of tropical cyclone forecasts as it applies to fleet operations on shore and at sea.

WORK COMPLETED

As an initial investigation into the framework of external/internal forcing of tropical cyclone inactivity, the spatial and temporal characteristics of the variability in the low-level zonal wind over the tropical western North Pacific, which had been shown by Harr and Elsberry (1991) to be related to tropical cyclone characteristics, was examined. Also, a climatological background of the basic statistical properties associated with periods of tropical cyclone inactivity was compiled to define the characteristics of an inactive period.

Based on co-located SSM/I and geostationary infrared data that had been processed for several periods of MCS activity that were related to tropical cyclone evolution, an index was defined to summarize the MCS life cycle. The index accounts for rain intensity, cloud area, and duration of convective and stratiform portions of the MCS.

Previously, a multivariate statistical classification of midlatitude circulation patterns was used to define characteristic types of extratropical transitions over the western North Pacific. Specific cases associated with each type of transition were identified and a comprehensive analysis package was constructed to examine various characteristics associated with the extratropical transition of a tropical cyclone into each type of midlatitude circulation pattern. Detailed analyses were completed of the internal and environmental influences on the transitioning tropical cyclone and on the eventual extratropical cyclone that results from the transition process.

The adequate preparation of a fleet asset for a tropical cyclone threat is based on two factors. The first is the receipt of accurate forecast information at lead times that allow for appropriate preparedness and the second is the capability of the asset's infrastructure to adequately prepare for the threat conditions. Based on these factors, decisions are made to either protect or not protect life and property, which is the so-called "cost/loss ratio" decision model. An alternative to the cost/loss type of decision process that may be applied to individual tropical cyclone threats is to examine the effect of all tropical cyclone impacts over a period of time. In this sense, a tropical cyclone represents a risk to the shore- or sea-based asset and the size of the risk is measured by the total impact of the tropical cyclone in terms of costs incurred to take protective action, plus any losses incurred during the period of impact. Over the time interval, a stochastic component, which is based on climatology, exists relative to the occurrence of the tropical cyclone and the size of the impact. Therefore, a risk model is defined to account for the variability in weather forecast information and natural variability associated with the occurrence of a tropical cyclone near a fleet facility.

RESULTS

Based on the analysis of Harr and Elsberry (1991) that related low-level zonal wind anomalies to tropical cyclone activity over the western North Pacific, a preliminary form of canonical correlation analysis (CCA) was applied (Harr et al., 1999c) to predict zonal wind anomalies over areas in which an empirical orthogonal function (EOF) analysis defined concentrations of zonal wind variability. The CCA loadings identified two preferred relationships that identified zonal wind anomalies over two consecutive pentads that could be used to predict the zonal wind three pentads in the future. These loadings could then be used to provide a measure of potential tropical cyclone activity and inactivity.

Co-located microwave and geostationary imagery were used to compile a detailed analysis of the evolution of MCS activity associated with several developing tropical cyclones and other MCSs within the large-scale monsoon trough environment of the western North Pacific (Harr et al. 1999b). The MCS index defined to account for rain intensity, cloud area, and convective and stratiform characteristics was combined with a measure of ability of the large-scale environment to contribute to MCS organization. Results indicated that although MCS characteristics define conditions favorable for structural features that could contribute to organization into a tropical cyclone, the organization did not occur until the contribution from the large-scale environment passed a specific threshold. These cases appeared to be representative of the evolution of a tropical cyclone that forms through mutual interaction of MCS activity and synoptic-scale forcing.

As a tropical cyclone moves poleward, the nearly symmetric tropical cyclone structure changes to one with large asymmetries in convection and wind distribution. The interaction between the midlatitude circulation tropical cyclone structure has been found to vary depending on the character of the midlatitude circulation. Harr et al. (1999a) defined two principal midlatitude circulation patterns based on whether an upper-level potential vorticity (PV) anomaly is located to the northwest or northeast of the poleward-moving tropical cyclone. Analysis of several tropical cyclones that moved into each type of midlatitude circulation was conducted (Harr and Elsberry 1999; Harr et al.1999a; Klein et al.1999) in terms of the distributions of heat and momentum fluxes, kinetic energy budgets, and three-dimensional frontogenesis. During transition into either circulation pattern, the tropical cyclone is initially impacted by upper-level eddy angular momentum fluxes associated with the juxtaposition of the midlatitude circulation. During transition into a northwest pattern, the tropical cyclone couples with the midlatitude baroclinic zone such that low-level eddy heat fluxes contribute to the extratropical development. Furthermore, there is both baroclinic and barotropic production of kinetic energy through direct solenoidal circulations that result from the coupling of the tropical cyclone and midlatitude trough. During transition into a northeast pattern, strong zonal flow between the upper-level PV center northeast of the tropical cyclone and the subtropical ridge southeast of the tropical cyclone prevents direct interaction between the decaying tropical cyclone and the midlatitude baroclinic environment. Also, transition into the northeast pattern results in barotropic destruction of kinetic energy that inhibits significant re-intensification.

A risk-model scenario was constructed for the occurrence of tropical cyclone-force winds at Kadena Air Force Base (AFB), Okinawa. In the risk model, the aggregation of tropical cyclone risk is treated as a compound stochastic process. The stochastic nature of the problem is parameterized in terms of the fluctuations in number of tropical cyclones that may impact the site and the size of the impact of each event. Initial results establish a change in costs that could be related to improved forecasts of position and timing of the impact at Kadena AFB.

IMPACTS

The preliminary application of the CCA to predict at a range of 10-15 days the zonal wind anomalies that are known to be related to tropical cyclone formation is expected to lead to a forecast technique that could be used for long-range outlooks of tropical cyclone activity and inactivity.

The definition of a MCS index and its relationship with a measure of the large-scale environment is hoped to lead to a systematic identification of potential MCS organization in the tropical cyclone environment.

In response to optimum-track ship routing factors, summer and early autumn trans-ocean maritime activity is often conducted at higher latitudes to take advantage of the climatologically favorable warm season wind and wave height conditions and significantly shorter route distances. Therefore, accurate analysis of the potential for extratropical transition and the cyclone characteristics associated with extratropical transition will help to improve forecasts of the intensity and movement of these systems, which may have significant impacts on maritime activities.

Identification of the value of forecasts concerning the impact of tropical cyclone conditions on fleet assets will help assess how forecasts might be improved and what physical characteristics need to be better understood to realize increased forecast value.

TRANSITIONS

It is expected that the integrated results of this investigation will be transitioned into a forecast system that JTWC will use to synthesize the potential for tropical cyclone formation and tropical cyclone structure and motion characteristics over the entire lifecycle of a tropical cyclone.

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